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THE NITRATE DEPOSITS OF CHILE

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LOCATION OF THE NITRATE REGIONS

The nitrate deposits of Chile are in the northern part of that country, in the region lying between about 19° and 26° south latitude, and mostly in the provinces of Tarapacá and Antofagasta. Some more or less isolated deposits have been found both north and south of these limits, but, as yet, have not proved of very great extent.[1] The Tarapacá region has been worked for a longer time, and at present supplies more nitrate than the Antofagasta region, but the latter is an important producer and has great future possibilities.

[1] Many changes have occurred in the last thirty years in the boundaries separating Chile, Peru, and Bolivia; and even provinces which bear the same names now as they did then may have different boundaries, so that different accounts of this region written at different times necessarily conflict in statements of boundaries and names. The data in the present paper are based on the boundaries of states and provinces as they now exist.

The nitrate deposits are found at intervals in an arid region known as the pampa, which runs north and south in a long narrow belt for almost five hundred miles between the Andes on the east and the Coast Range on the west, and from a few miles to over one hundred miles inland.

During the year 1907 the writer visited some of the nitrate regions of northern Chile, and the present paper embodies his investigations there. The remarks apply mostly to the Tarapacá region, unless otherwise stated, as that was the only part of the field carefully studied. There is, however, much similarity in many of the features of the nitrate deposits in both Tarapacá and Antofagasta, though in some respects they differ considerably.

HISTORY OF THE NITRATE MINING INDUSTRY

The nitrate deposits of Chile have probably been known from very ancient times, but the extensive mining and utilization of them is a comparatively modern industry. During the wars for independence which the countries on the west coast of South America waged against Spain in the early part of the nineteenth century, the nitrates are said to have been utilized to make niter for gunpowder. The first operations to handle nitrate on any considerable scale, however, are said to have been started by a Frenchman named Hector Bacque, at La Noria, in Tarapacá, about 1826.[1] This enterprise was followed by a number of others, and in the next fifty years, many similar operations were started by Europeans, Americans, and Chileans.

The early enterprises were all in what is now the province of Tarapacá, a region which at that time belonged to Peru, and which was supposed to be the only part of this coast that contained nitrate; but as the industry grew and began to attract more general notice, search was made for nitrate elsewhere. The result was the discovery of deposits in the province of Antofagasta, lying south of Peruvian territory, and active mining operations were soon started there. At this time, the northern part of what is now Antofagasta belonged to Bolivia and the southern part to Chile. The Chilean government, recognizing the importance of the new discoveries, sent out a commission to investigate the occurrence of nitrate in Chilean

[1] G. F. Scott Elliot, *Chile*, p. 259.

territory. The report of this commission was published by the government and was printed in English, in London, in 1878. It shows that at that time active mining was going on both in Bolivia and in the adjoining Chilean territory. In both regions, Chilean capital and Chilean labor were employed to a large extent.

As the industry grew, Bolivia imposed an export tax on the nitrate shipped from her territory, which Chile considered inconsistent with certain treaty rights existing between the two countries. Chile protested against the injury done by the tax to her citizens engaged in the industry in Bolivian territory, but Bolivia continued the tax and war ensued in 1879. Peru was in alliance with Bolivia at that time and hence became involved in the fight with Chile. The war lasted until 1883 when peace was declared. Chile had been victorious on all sides, and after the war she annexed the two southern provinces of Peru, known as Tacna and Tarapacá, and the Bolivian province of Antofagasta, thus adding not only several hundred miles to the northern extension of her possessions, but also gaining control of all the known nitrate districts of the west coast of South America.

After the close of the war, the nitrate industry became much more active than formerly. New capital poured into the country and the deposits were rapidly developed. Mr. G. B. Chase, of the United States, and Colonel J. T. North, of England, were among the most active foreign operators, while the Chileans themselves were very energetic in developing the region. The Germans also have acquired large interests in the nitrate fields and are active operators, but the English companies are by far the most numerous of all. Though Americans were among the pioneers in the industry, their operations at present are small compared with those of the English, Germans, and Chileans.

NATURAL FEATURES OF THE NITRATE REGIONS

Chile extends along the west coast of South America in a long narrow belt from Peru southward to Cape Horn, a distance of almost 3,000 miles. In width it varies from less than 100 miles to rarely over 200 miles. It is essentially a mountainous region, being occupied on the east by the main range of the Andes, and on the west by the Coast Range. The Andes rise in rugged peaks to altitudes of from

10,000 to over 20,000 feet, while the Coast Range is lower, from 3,000 to 7,000 feet, though sometimes more. The Coast Range is often characterized by rounded summits and smooth slopes, in marked contrast with the bold angular contour of the Andes. In some places the Coast Range is prominently marked, while in others it is little more than the escarpment of an interior plateau as it breaks off to the sea.

Both the Andes and Coast Range follow a general north-and-south course, and between them is an intervening belt of lower country known as the central or longitudinal valley. This so-called valley, however, is not a single continuous drainage area bordered by two mountain ranges as might be supposed, but is a series of elevated basins, forming rolling plains or plateaus, more or less separated by transverse ranges, and draining independently of each other into the Pacific Ocean. In some places the mountains on the east and west approach so closely to each other that their foothills blend together, almost obliterating the intervening basin region; in other places they separate, and the basin region broadens out to many miles in width (see map, Fig. 1).

In northern Chile this basin region is especially well marked in the provinces of Tarapacá, Antofagasta, and northern Atacama. It is here an elevated arid country and includes the Tamarugal Desert on the north and the Desert of Atacama on the south.[1] It is of a generally flat or undulating character, from less than 2,500 feet to over twice that height above the sea, and studded with small, rounded hills, some of which rise considerably higher than the surrounding plateau (see Fig. 2). Its surface is dry and sandy, very few streams intersect its parched expanse, and vegetation is almost totally absent.[2] This region is known as the *pampa*, a term applied somewhat indiscriminately not only to the whole arid region, but

[1] The Tamarugal Desert includes most of the interior basin region of the province of Tarapacá and the northern part of the province of Antofagasta. The Desert of Atacama includes the southern part of Antofagasta and the northern part of the province of Atacama.

[2] Farther south, in central Chile, the basin or valley region becomes a rich fertile country under the influence of the plentiful rainfall there; and still farther south, in southern Chile, where the basin region is more or less submerged in the ocean, the rainfall increases so much as to make one of the wettest parts of the world; but in this northern section the dry desert character of the country is its distinguishing feature.

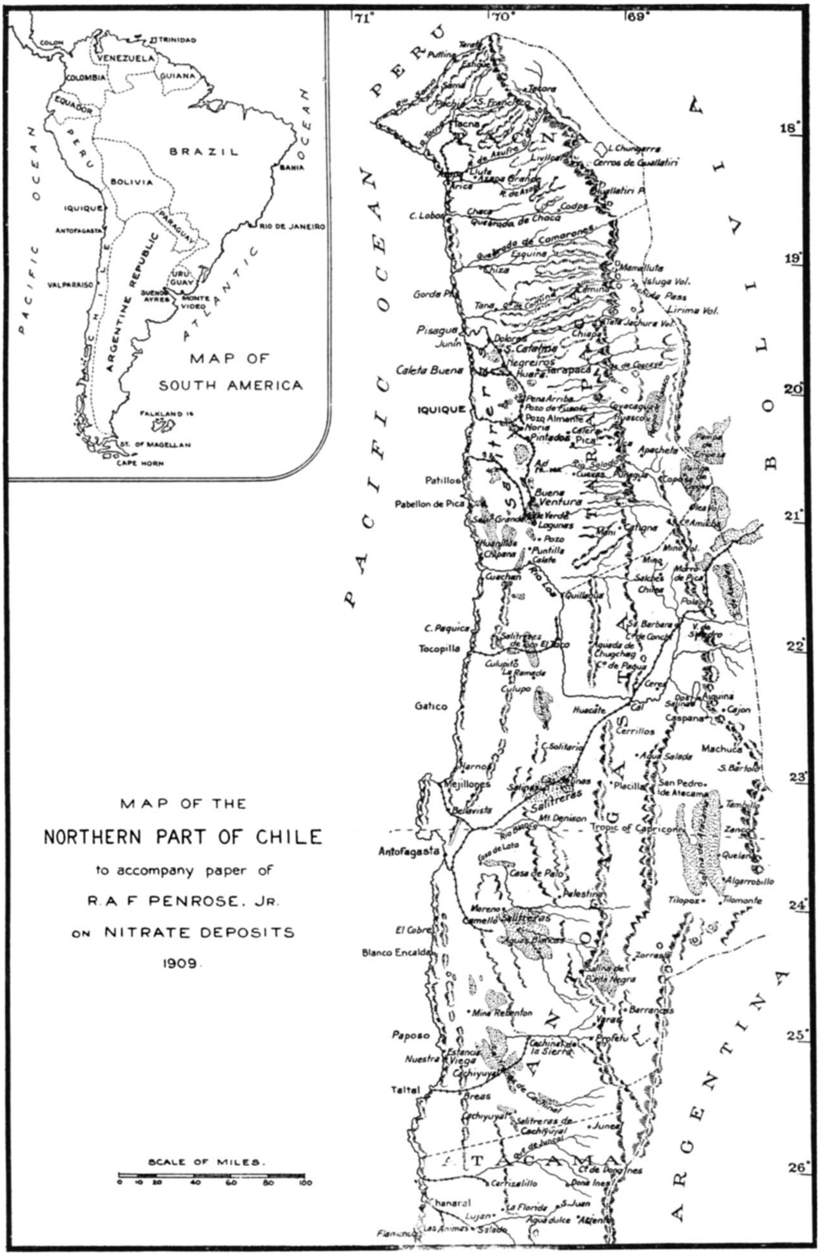

FIG. 1.—Map of northern Chile.

also to special parts of it, either large or small. Thus the term Tamarugal Pampa applies to a large part of the basin of Tarapacá and northern Antofagasta, while the term Tarapacá Pampa applies only to the part of the basin region in the province of that name; and the terms Huara Pampa, El Toco Pampa, Taltal Pampa, and many others apply to purely local districts.

Rain is very rare in the pampa, frequently three or four years, and sometimes eight or ten years of unbroken drought occurring. The Coast Range in this part of Chile is almost as dry as the pampa, though fogs from the ocean are common, and their moistening influence encourages the growth of a little grass and a few cacti on the tops of the hills. Even the fogs, however, rarely reach the pampa. Many streams flow westward from the Andes, but most of them rapidly evaporate or sink below the surface when they come to the pampa, and hence a map of the region shows them suddenly terminating at the foot of the mountains (see map, Fig. 1). The waters that sink continue westward underground, occasionally rising near enough to the surface to form oases in the desert, and then disappearing again. In times of high water, some streams reach the sea on the surface, but only very few do so perennially. Sometimes during seasons of great rises in the rivers of the Andes, the pampa is flooded over large areas. Such occurrences are rare, though some have been recorded, and evidence of them is seen in the dry gullies running across the pampa and in the local accumulations of drift wood from the Andes. In past ages these floods were probably more frequent than now, but the normal condition of the pampa today is one of great aridity. The very presence of nitrate deposits is evidence of the extreme dryness of the region, for nitrate is easily soluble, and water would soon dissolve it and carry it away. The only vegetation is in a few isolated spots where underground streams rise near enough to the surface to support the growth of a little grass or a few stunted trees. Elsewhere the pampa is a sandy desert, from which an impalpable dust rises in blinding clouds with the slightest wind and where the drifting sands form immense dunes similar to those seen on the coast.

The surface of the pampa is composed mostly of sand, clay, and gravel, with masses of more or less rounded rock fragments scattered

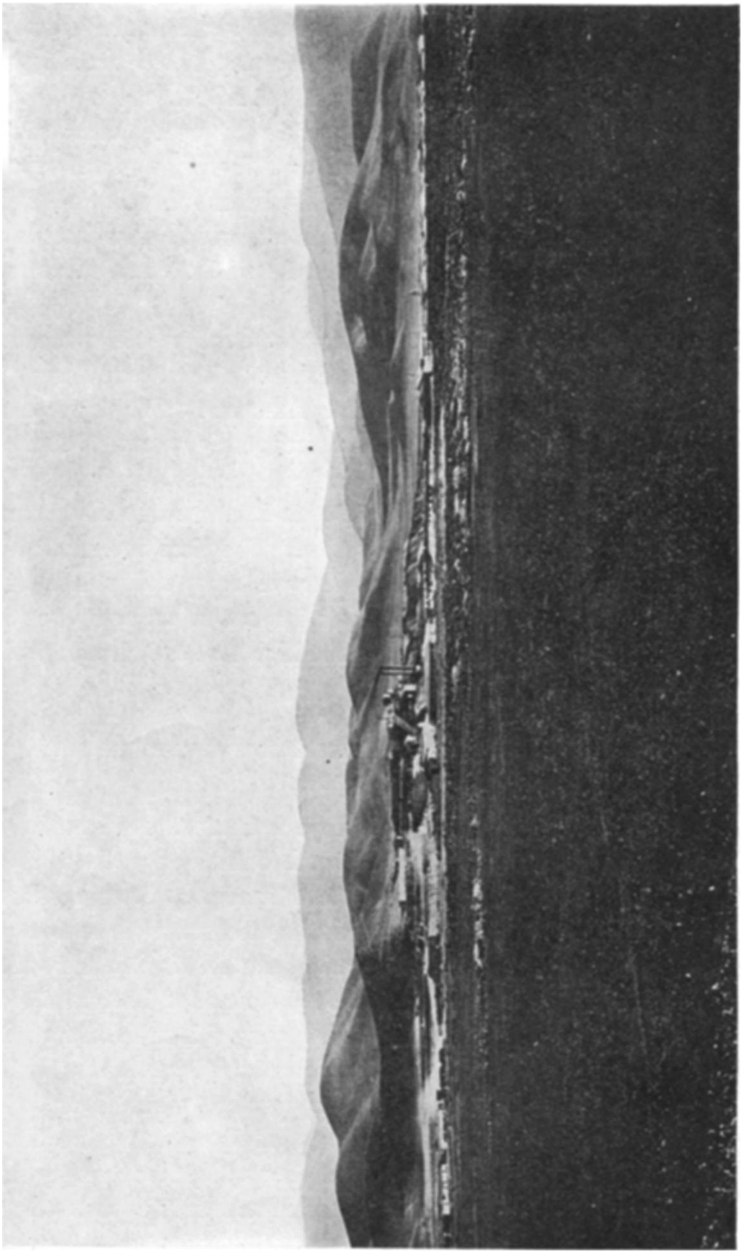

FIG. 2.—Typical view in the pampa of the province of Tarapacá, Chile, showing the nitrate deposits near the base of the low hills, and the Coast Range in the far distance.

over it, and frequent deposits of saline materials. Through these loose materials frequently protrude isolated hills and knolls of stratified and igneous rocks similar in nature to many of the rocks found in the adjoining mountain ranges; and doubtless rocks of like character underlie the loose sediments of the pampa. The surface materials of the pampa are probably of post-Tertiary age and represent an old sea bottom formed by the deposition of sediments in a now extinct inland sea, or a series of lakes, which once extended from the Andes to the Coast Range, over the whole extent of what is now the pampa.

The Coast Range bordering the pampa on the west is composed of a variety of rocks varying greatly in different places from Tarapacá southward through Antofagasta and Atacama. Old crystalline rocks, including gneisses, granites, etc., frequently occur. Stratified rocks of probably both Paleozoic and Mesozoic ages, including sandstones, limestones, and shales, are abundant in many places, and are much folded, contorted, and broken. They are intersected in many places by igneous intrusions. As we cross the pampa and approach the Andes, both stratified and igneous rocks again appear through the loose sediments; and in the high Andes immense areas of late volcanic flows are found.

MODE OF OCCURRENCE OF THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The pampa region has a general slope from east to west, that is, from the foot of the Andes to the foot of the Coast Range, though it is so gradual as to be often unnoticeable to the eye. As a result of this slope the lowest part of the pampa is along its western border, where it abuts against the Coast Range foothills. It is along this zone that the nitrate deposits occur, and in the province of Tarapacá they occupy a narrow north-and-south belt following this position for over one hundred miles. The surface of the pampa is here almost always impregnated with more or less saline matter, which sometimes becomes so abundant as to form beds several or many feet in thickness. These are practically superficial deposits, though they are sometimes capped by earthy materials for some feet in depth. Their surface, when exposed, often presents a rough and more or less

leached appearance, due to the action of the rains and floods which at rare periods visit the pampa (see Fig. 3). Sink holes, due to the same cause, are not infrequent. Most of the deposits consist of common salt (sodium chloride) or of nitrate (sodium nitrate), or of both mixed together; while other saline materials occur more sparingly. The salt beds are called by the Chilean *salares* and the nitrate beds, *salitreras*. The material composing the nitrate beds is known as *caliche.*

Though both common salt and nitrate occur in very large quantities, the former is by far the more abundant, and covers immense flats for many square miles in area along the western edge of the pampa. Sometimes it is in comparatively pure beds, sometimes it is mixed with clay, sand, and gravel, and sometimes it only impregnates the surface of the pampa. These salt beds have not yet been extensively explored, but they probably vary from a mere crust to several or even many feet in thickness. The salt is not much used, though a little is obtained for local consumption and is refined by dissolving and evaporating the solution.

The nitrate deposits, though less extensive than the common salt deposits, are far more important commercially. Like them, they occur in the low zone along the western edge of the pampa, but while the salt flats are usually in the very bottoms of the basins, the nitrate deposits are usually on a little higher ground. Sometimes the nitrate deposits also occupy the bottoms of the basins, but their typical position is on the lower slopes of the hills and ridges, forming terraces or benches around the salt flats, and from a few feet to perhaps one hundred feet or more above them. Sometimes there may be nitrate upon the slopes and no salt in the flats, and sometimes there may be salt in the flats and no nitrate on the slopes, while sometimes the deposits of the two materials are more or less indiscriminately mixed or may underlie or overlie each other; but in many cases we find them both occupying the respective typical positions just mentioned. The slopes on which the nitrate often occurs rise at low angles and are sometimes scarcely distinguishable from the surrounding flat country.

The nitrate deposits are of very variable thickness even over small areas, and in one spot there may be several feet of the material, while within a few yards there may be only a few inches, or none at all.

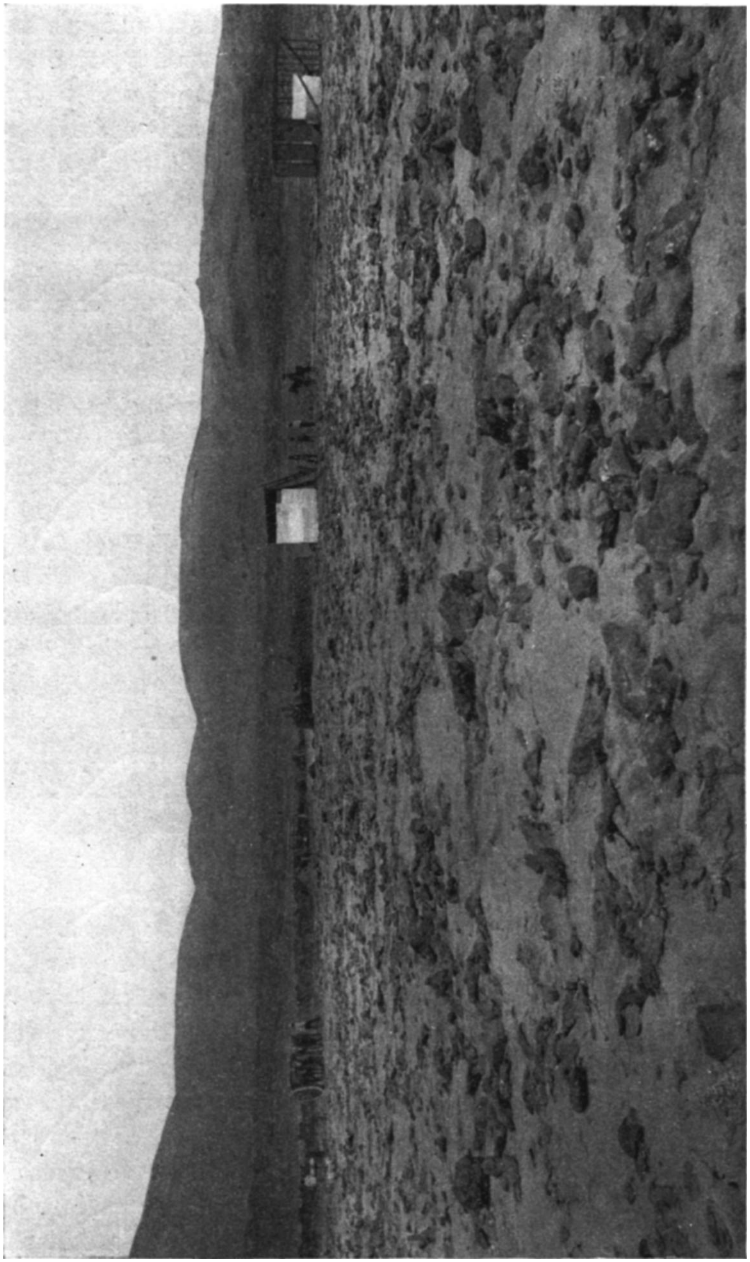

FIG. 3.—View in the pampa of the province of Tarapacá, Chile, showing characteristic surface features of the salt and nitrate deposits.

A thickness of from 1 to 1½ feet is common, of 2 to 3 feet is less so, but not unusual, and of 4 to 6 feet is very unusual. Where the surface of a deposit is not too heavily covered with earthy materials, it often has a moist appearance due to the deliquescent character of the nitrate or perhaps to the presence of calcium chloride.

The nitrate deposits are usually covered by a capping composed of sand, clay, gravel, and rock fragments, from a few inches to many feet in thickness. In a few places this capping is absent and the nitrate is covered only by a thin coating of desert dust, but usually the overlying material is from 2 to 20 feet in thickness and sometimes, though rarely, 30 to 40 feet. This capping is called *costra* and is generally more or less indurated; the usual condition being alternating layers or patches of harder and softer material, and an extreme condition being that of a hard mass like a breccia or conglomerate, in which the cementing material is nitrate and other saline and earthy substances. The rock fragments are angular or partly rounded and vary from the size of grains of wheat to masses of a foot or more in diameter, pieces from a half-inch to 3 inches in diameter being the most common. The fragments consist of limestone, shale, sandstone, igneous rocks, etc., the preponderance of one or the other varying in different places. They seem to some extent to vary in character according to the nature of the rocks *in situ* in the neighborhood, and seem to have been derived largely from the slopes of the Coast Range hills and from the small knobs protruding up through the pampa. The costra is often overlaid by from a few inches to a few feet of loose, wind-drifted material called *chuca.*

In some places there is a sharp line of demarkation between the costra and the nitrate; in others they seem to blend into each other. In fact, they often seem to represent one and the same deposit, rich in nitrate at the base and poor in nitrate above. The smaller quantity of nitrate in the costra than below may possibly be due to impoverishment by leaching during the rare periods of rainfall or flood. In a few of the mines where the rich part has been exhausted, the costra has been worked as a source of nitrate. Underlying the nitrate is an earthy material of a brown or buff color, generally soft and powdery though sometimes sandy, gravelly, or indurated, called *coba.* Below

the coba is the great series of interbedded sands, clays, and gravels which underlie the broad expanse of the pampa.

A general section of the nitrate deposits in Tarapacá, therefore, would show the following succession of formations:

"Chuca" (loose, wind-blown material, dust, sand, gravel, etc.)	0–several feet
"Costra" (capping of the nitrate beds)	0–20 or even 30 or 40 feet
"Caliche" (crude nitrate)	0–6 feet
"Coba" (earthy floor of nitrate beds)	Indefinite (perhaps a few feet)
Stratified sands, clays, and gravels	To great depths

In a few places the nitrate occurs as a fringe around the edges of the isolated knobs of rock that rise up through the pampa, and rests either on the solid rock or on the detritus of the hillside, but its usual occurrence is overlying the earthy materials described above.

MATERIALS COMPOSING THE NITRATE DEPOSITS IN THE TARAPACÁ REGION

The nitrate occurs in the form of sodium nitrate with the formula $NaNO_3$, though very small quantities of other nitrates are sometimes found with it. It generally occurs as a translucent mass, sometimes in a coarsely or minutely crystalline aggregate of rhombohedra; sometimes in a stalactitic or mammillary form, or as an efflorescence or incrustation. When pure, it is of a white color, but is often yellow, red, brown, or purple from impurities. Frequently it is much streaked or spotted a dirty brown color due to sand or clay, and sometimes it is so mixed with earthy matter as to have a chocolate-brown appearance throughout. The crude material, as already stated, is known by the Chileans as caliche. Its mineralogical name is soda niter or nitratine. Sometimes it is called cubic niter or cubic saltpeter, because on casual inspection its rhombohedral crystals seem closely to approach the form of cubes. Commercially it is often known as Chile saltpeter, as distinguished from plain saltpeter, or niter, which is potassium nitrate.

The nitrate deposits are never composed of perfectly pure sodium nitrate, that material forming usually only from a small percentage up to rarely as much as 70 per cent. of the whole mass. Crude nitrate containing 25 per cent. of sodium nitrate is considered a fair grade of raw material, one containing 50 per cent. is considered high,

and one containing 60 or 70 per cent. is very rare, though of course in selected specimens even 90 per cent. or more of sodium nitrate may be found. The impurities are sand, clay, gravel, and rock fragments, with a very variable admixture of saline materials. The rock fragments are similar to those already described in the costra, overlying the nitrate. In some places they are scattered only sparingly through the deposits; in others they are so numerous as to form a breccia or conglomerate with the nitrate as a matrix.

The saline impurities in the nitrate are mostly common salt (sodium chloride), with variable amounts of sodium sulphate (Glauber salts) and calcium sulphate, the latter often occurring as crystalline gypsum and perhaps also as anhydrite. In addition, there occur sodium and calcium borates, as well as carbonate, chloride, and other salts of calcium, and various salts of aluminum, magnesium, potassium, ammonium, and a small but very constant quantity of sodium iodate. Bromine compounds, together with other materials in small quantities, are sometimes, though more rarely, present. The common salt (sodium chloride) occurs in varying amounts in all the nitrate deposits, sometimes in very large quantities, and we find all gradations in admixture from deposits composed mostly of nitrate to deposits composed mostly of salt. The other saline materials are in comparatively small amounts, though in special cases some of them may be more abundant than the common salt.

The following analyses represent the composition of samples of crude nitrate (caliche) from different localities. The analyses were made in Chile by Mr. D. G. Buchanan, chemist of the Alianza Company, and were kindly sent to the writer by Mr. J. F. Comber, manager of the North Lagunas Company.

The saline impurities in the crude nitrate are generally purely mechanical admixtures, like the salt, but sometimes they are associated with the nitrate in certain proportional relations, forming distinct minerals. Thus we have darapskite and nitroglauberite, both minerals consisting of hydrous nitrates and sulphates of sodium. Moreover, both the nitrogen and the iodine occur in small quantities in other combinations than with sodium. Small amounts of potassium nitrate are often found, while calcium nitrate (nitrocalcite) and barium nitrate (nitrobarite) as well as calcium iodate (lautarite) and

a calcium iodo-chromate (dietzeite) also occur. These and other rare combinations that are found in the region are, however, in small quantities and are only mineralogical curiosities.

The iodine in the crude nitrate is an important material on account of its commercial value. It is a very constant ingredient in the deposits, though in minute quantities, generally only a fraction of 1 per cent., and occurs usually in the form of sodium iodate, though a little sodium iodide has also been found. Sometimes the iodine is

ANALYSES OF CRUDE NITRATE (CALICHE) FROM CHILE

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sodium nitrate..........	28.54	53.50	41.12	61.97	22.73	24.90	27.08
Potassium nitrate........	trace	17.25	3.43	5.15	1.65	2.50	1.34
Sodium chloride.........	17.20	21.28	3.58	27.55	41.90	24.50	8.95
Calcium chloride........	.....	.....	.....	.....	.....	.....	5.25
Magnesium chloride.....	.....	.....	.....	.....	.....	.....	0.18
Potassium perchlorate ..	trace	0.78	0.75	0.21	trace	trace	trace
Sodium sulphate........	5.40	1.93	trace	2.13	0.94	6.50	none
Magnesium sulphate.....	3.43	1.35	10.05	0.15	3.13	6.50	none
Calcium sulphate........	2.67	0.48	3.86	0.41	4.80	4.50	2.89
Sodium bi-borate........	0.49	0.56	0.20	0.43	0.53	0.15	0.52
Sodium iodide..........	0.047	.....	.....	.....	.....	.....	.....
Sodium iodate..........	0.043	0.01	0.05	0.94	0.07	0.054	0.08
Ammonium salts........	trace	trace	trace	trace	trace	trace	trace
Sodium chromate........	.....	trace	.....	distinct traces	trace	.....	.....
Insoluble matter.........	40.30	2.07	31.86	0.39	22.50	28.40	47.34
Combined water, etc.....	1.88	0.79	5.00	0.67	1.75	2.00	6.37
	100.00	100.00	100.00	100.00	100.00	100.004	100.00
Total nitrates calculated as sodium nitrate......	28.54	68.00	44.02	66.29	24.11	27.00	28.20
Total chlorides calculated as sodium chloride	17.20	21.28	3.58	27.55	41.90	24.50	14.70
Total iodine............	0.067	0.0064	0.036	0.604	0.045	0.035	0.051

more abundant in the salt deposits than in the nitrate deposits, but the market demand is supplied by what is obtained as a by-product in refining the nitrate, and hence the salt is not worked for iodine. Borates occur in many places throughout the arid region of the pampa, mostly in the form of the hydrous borate of sodium and calcium known as ulexite or boronatrocalcite, or in the form of the hydrous calcium borate known as colemanite. In places these materials have been worked to a very considerable extent. Some sodium bi-borate is also found. Sodium sulphate occurs in large deposits

in parts of the pampa, especially in Antofagasta, but is not worked on account of the limited demand for it. There are many materials in the pampa, such as potassium salts, etc., which would be of great value if found in quantities, but, so far as yet known, they occur too sparingly to be of any considerable commercial importance.

To summarize, it may be said that the commercial products of the pampa are mostly sodium nitrate, with comparatively small, but commercially very important, quantities of iodine; while common salt is obtained on a small scale for local use, and borates have been produced in varying quantities at different times, often in very important amounts. The production, however, of all the other saline materials in the pampa is insignificant in importance compared with that of sodium nitrate.

OTHER NITRATE REGIONS IN CHILE

As already stated, almost all the nitrate of Chile is in the great arid basin lying between the Andes and the Coast Ranges, in the provinces of Tarapacá and Antofagasta. South of the nitrate fields of Tarapacá, already described, the main pampa region extends through the province of Antofagasta and here several large nitrate fields occur. A number of transverse ridges, or ranges of hills, intersect this region, forming more or less separated basins, and it is in these that the nitrate occurs. The different basins are designated as different pampas, but all of them are simply parts of the general pampa region.

The El Toco Pampa is in the northern part of the province of Antofagasta, and here large deposits of nitrate are actively worked. The refined product is shipped from Tocopilla, a seaport about 120 odd miles south of Iquique, and connected with the nitrate district by a railway. Farther south in the same province are the Antofagasta Pampa and the Aguas Blancas Pampa. Both are large producers of nitrate, and are connected by railway with the port of Antofagasta, which is the shipping-point for the nitrate from these districts and is an important city of about 20,000 people. Recently also a new port called Mejillones, a few miles north of the port of Antofagasta, has been improved and connected with the railway running into the nitrate fields, in order to facilitate shipments. Still farther south,

in the extreme southern part of the province of Antofagasta, is the Taltal or Cachinal Pampa, where large quantities of nitrate are also produced. A railway connects this district with the coast at Taltal, which is a prosperous seaport in the southern part of the province of Antofagasta and the shipping-point for the Taltal district.

Though most of the nitrate deposits of Chile are in the provinces of Tarapacá and Antofagasta, yet some have been found to the north and south of these limits. As yet, however, they have not become of great importance. In the province of Tacna, to the north of the province of Tarapacá, several small pampas represent a northerly continuation of the general pampa region, and a few small nitrate deposits have been found there. South of the province of Antofagasta, isolated nitrate deposits have been reported in places in the northern part of the province of Atacama, but the extent of the deposits is not yet well defined.

ORIGIN OF THE NITRATE DEPOSITS OF CHILE

The discussion of the origin of the nitrates of Chile involves chiefly the source of the nitrogen, and many suggestions have been advanced to explain its presence, but its derivation from organic matter, and especially from guano, seems the most probable hypothesis. Among some of the other hypotheses that have been suggested may be mentioned the following:

It is a well-known fact that electric storms have the power of causing the oxidation of the nitrogen of the air with the formation of nitric acid. It has been suggested by some that such storms in the Andes have generated nitric acid, which, coming in contact with the limestone found in places in the mountains, has formed calcium nitrate; and that this has in turn been converted to sodium nitrate by contact with sodium salts found in the pampa region.

It has also been suggested that the nitrogen of the nitrates was derived from nitrogenous fumes from volcanoes in the Andes.

A. Pissis[1] quotes authority to show that alkaline carbonates have the power "of transforming atmospheric nitrogen into nitric acid in the presence of other oxidizable matters." He points out that the decay of feldspar in the rocks of the region has supplied a source

[1] *Nitrate and Guano Deposits in the Desert of Atacama*, London, 1878, p. 16.

of alkaline carbonates, that the protoxide compounds of iron, which are common in the rocks of the pampa, are easily oxidized under ordinary conditions forming peroxide compounds of iron, and he thinks that the alkaline carbonates, under such environment, have caused the oxidation of the nitrogen of the air with the ultimate formation of nitrates.

David Forbes[1] thinks that the nitrates were derived from the decay of vegetation around and in salt water swamps and lagoons, which he believes once occupied the site of the present pampa. A certain amount of nitrogenous matter might be derived in such a manner, and this subject will be discussed again later on.

It seems, however, as if a source of nitrogen more abundant and ready than any of those mentioned might have existed in the immense accumulations of guano which for ages have been characteristic of this coast, and this suggestion has been offered by a number of other writers. Incidentally it may be stated that in many parts of the world, especially in warm regions, nitrates are found in small deposits in caves, in association with bat guano, and that the source of the nitrogen from this guano is very generally recognized.[2]

It is well known that the part of the coast of Chile where the nitrates occur has been gradually rising in recent geologic times, and that the pampa region already described was once a part of the ocean bottom. During this elevation, as the region gradually rose up to, and then above, the ocean level, it probably passed first through the condition of an open bay or gulf, then became more and more separated from the ocean, and finally, when raised completely above it, became a more or less inclosed interior basin occupied by an inland sea, or a series of basins occupied by salt lakes, lying between the Andes and the Coast Range. Guano beds were doubtless deposited along the borders of these waters, just as they are now deposited on the neighboring shores of the Pacific.

Guano consists largely of nitrogenous materials, phosphates, and water, with other substances in smaller quantities. The nitroge-

[1] "On the Geology of Bolivia and Peru," *Quarterly Journal of the Geological Society of London*, Vol. XVII (1860–61), pp. 13–16.

[2] A. Muntz et V. Marcano, *Académie des Sciences, Comptes Rendus*, Vol. CI (1885), pp. 65–68. See also A. Muntz, *ibid.*, pp. 1265–67.

nous materials consist mostly of ammonium salts, especially of urate of ammonium, and other urates, together with guanine[1] and variable quantities of nitrates and nitrites, as well as with various other organic products resulting from decayed animal matter. It is a well-known fact that, under suitable conditions, the nitrogen of all these materials that are not already in the form of nitrates, passes eventually into that form through the agency of certain microscopic organisms (bacteria). These bacteria are of many different kinds, and different ones act at different stages in the transition. The action, when other conditions are favorable, goes on most efficiently in the presence of alkalies, or of alkaline earths like calcium carbonate, etc., which are abundant in the pampa region.

It seems probable that the nitrates of Chile were mostly produced in this way from nitrogenous animal matter of old guano beds which once lined the waters of the interior basin, and which have long since disappeared under the influence of erosion. The nitrates were probably carried down into the waters of the basin and became mixed with the other saline materials already there. The waters probably began to diminish in volume shortly after their separation from the sea, for though they received the drainage of the surrounding land, this was not enough to compensate for the loss by evaporation. The evidence tends to show that the rainfall in those early days was more abundant in this region than at present, but it gradually grew less and its constant diminution doubtless hastened the process of desiccation.

Thus the waters gradually sank until they fell below the level of any outlet they may have had to the ocean, and then, the drainage being cut off, the materials in solution became more and more concentrated as desiccation progressed. These materials consisted of the original salts of the sea water, the nitrates and other salts from the guano beds, and other materials constantly carried down from the surrounding land. The concentration continued until the waters became saturated with saline materials, and then deposition began along the edges and on the bottom. Eventually the whole body of water disappeared and the dry desert pampa with its deposits of nitrates, common salt (sodium chloride), and other materials alone

[1] Guanine is an organic base containing nitrogen and having the formula $C_5H_5N_5O$.

remained. The occurrence of the nitrate in the form of sodium nitrate is probably due to the abundance of sodium salts in the region.

The occurrence of the nitrate and other saline deposits along the western edge of the pampa, where the latter is lowest in altitude, may be due to one or both of two causes:

1. The pampa, sloping as it does from east to west, gradually caused the last of the waters of the inland basin, as they evaporated, to collect along its western edge. If the nitrate in solution had not become sufficiently concentrated to cause deposition before that time, the deposits of course would be formed only on the west side.

2. If, however, deposition had begun while the waters still washed the slopes of the Andes, the greater rainfall there than on the west side of the pampa may have dissolved the nitrate from the east side and allowed it to be carried down into the loose soil of the pampa, or else over to the west side, where it was again deposited as the waters evaporated.

As against the hypothesis of the derivation of the nitrates of Chile from guano, the objection has been made that guano beds, and the remains of dead birds such as generally occur in them, are often notably absent in some of the nitrate districts. Very little guano is found with the Tarapacá nitrates, but in Antofagasta it does occur in the same region as some of the nitrate deposits. The scarcity of guano at present in some of the regions is easily explained, for the birds which formed it were essentially sea birds, dependent upon fish for food. As the waters of the inclosed basin gradually evaporated they became too saturated with saline matter for fish to live in them, so that the birds had to abandon their old haunts in the basin and seek other regions for their sustenance. Hence, though immense accumulations of guano had probably been formed, no new supply was maintained, and ample time has elapsed for the old guano to have been carried away, as already described, and for the bones, etc., to have disintegrated. The fact that guano is still abundant in parts of the nitrate regions of Antofagasta and not so in Tarapacá probably indicates that the birds left the latter region at an earlier date than the former, or that the conditions for its preservation were better in Antofagasta than Tarapacá.

The notable absence of seashells and remains of other marine

life in the nitrates of Tarapacá, may be explained in a manner similar to that suggested for the absence of guano, that is, the water became too heavily charged with saline matter for such life to exist, and the remnants of what had previously existed were gradually destroyed or were covered up by later pampa deposits.

If the nitrate was derived, as already described, from old guano beds long since disintegrated and eroded, then we might expect to find phosphates from the same source concentrated somewhere on the pampa; but such, so far as known, is not the case, though of course phosphates are found in the still existing later guano. Perhaps, however, phosphates from the old eroded guano may exist, and may not yet have been discovered, as the pampa has been but little studied outside its nitrate deposits. As the phosphates in guano are both soluble and insoluble, some of the former derived from the old guano may possibly have percolated into the limestone existing in parts of the region, forming insoluble calcium phosphate, such as occurs in coral formations in the West Indies and the South Sea Islands; while perhaps some of the insoluble phosphates resulting from the old guano may yet be found among the sediments of the sea bottom which now forms the pampa.

It is possible that in addition to the nitrate derived from guano, a small amount of it may have been derived from the decay of the marine and land vegetation of the interior basin. This decay would set free nitrogenous vegetable materials from which nitrates might have been formed, just as from guano. Nitrogen, however, is much more abundant in guano than in vegetable matter, and, therefore, the probability seems to be that guano was by far the more important source of the nitrates. Marine vegetation, however, probably played a most important part in supplying the iodine found in the region.

The source of the iodine in the nitrate and salt deposits of the pampa has been a much-discussed subject. Iodine is a constituent of many minerals and is found in many mineral springs, as well as in minute quantities in sea water. It also enters in small but appreciable quantities into the composition of certain marine plants and some sea animals. In fact before the iodine of Chile came into use, most of the iodine of commerce was extracted from

certain forms of seaweed or kelp. Iodine is taken up by such plants from the sea water and fixed in their tissues.

The iodine may, therefore, have come either from sources on the land or in the water or both. As yet no strong evidence has been produced to show that it came from the land. On the other hand, we have no definite evidence that it came from marine sources, but at the same time we know that the pampa was formerly probably covered by a body of sea water, at first connected with the open ocean and later cut off from it. During the time that it was more or less directly connected with the ocean an immense accumulation of iodine-bearing marine plants may have grown there, gradually collecting the iodine not only from the limited quantity of water represented by the arm of the sea in which the plants grew, but also from a constant fresh supply of sea water circulating in and out from the ocean, or dashed over a possible dividing barrier during storms and high tides. Possibly also similar marine plants from the open ocean may have come in with this sea water and accumulated, in a manner similar to that seen in many parts of the world today, thus augmenting the marine plants already growing there. After the region had been completely cut off from the ocean and desiccation had progressed sufficiently, this marine flora would decay and thus afford a great quantity of iodine. The simple evaporation of the water of the inclosed basin would of course account for some of the iodine, as this material is universally present in sea water, but in quantities so extremely minute that it seems necessary to suppose that the iodine of the pampa has been segregated from far larger quantities of water than those of the basin alone.

Hence, though the possibility of the source of the iodine from the decay of iodine-bearing minerals or springs on the land cannot be denied, yet the facts at hand suggest more strongly a source from marine plants.

As regards the borates found in the pampa, it may be said that, like the borates found under similar conditions in many other arid regions, they were probably derived mostly from the decay of boron-bearing minerals and from springs carrying boron compounds, such as are common in many mountainous regions, and especially those of igneous origin. Boron compounds occur also in sea water and

in some plants, but in quantities so extremely minute as to make such sources answerable for only a very small amount of the borates of the pampa. On the other hand, when we consider the vast areas of igneous rocks in the Andes and even in the Coast Range, the source mostly from boron-bearing minerals and springs seems very plausible. The boron materials from such sources were probably carried down into the waters of the inland basin, where they were concentrated and deposited in the same manner as the other saline materials.

In concluding the subject of the origin of the nitrates and other saline deposits of the pampa, it must be said that the present discussion is intended only as a most brief and general one. A vast amount of geological and chemical details must be worked out both in the field and the laboratory before the subject can be fully understood. The determination of the exact conditions of deposition and the various chemical transitions through which the saline materials have gone, require far more data than are at present available.

INDUSTRIAL FEATURES IN THE TARAPACÁ REGION

Mining and refining of nitrate.—Mining in the nitrate regions is done in surface openings. The capping of costra is thrown aside and the nitrate below mined and raised to the surface (see Figs. 4 and 5). The quantity of nitrate often varies greatly in different parts of a deposit and the change from rich spots to lean spots is often very abrupt, so that nitrate is usually worked in isolated pits or short trenches on the spots where it is richest, and not in long trenches running systematically through the deposit, as would be the most economical way if the deposits were uniform. Hence, most properties that have been extensively worked present the appearance of an upturned tract studded with numerous pits, some close together and some more or less separated. In some cases, where the capping of costra is hard and compact, or very thick, the miner finds it easier to go under it in search for nitrate than to remove it, and thus small underground workings in the form of caves have sometimes been formed, but these are the exception, and the usual mining is in open pits.

When the richest parts of a deposit have been exhausted, the miner

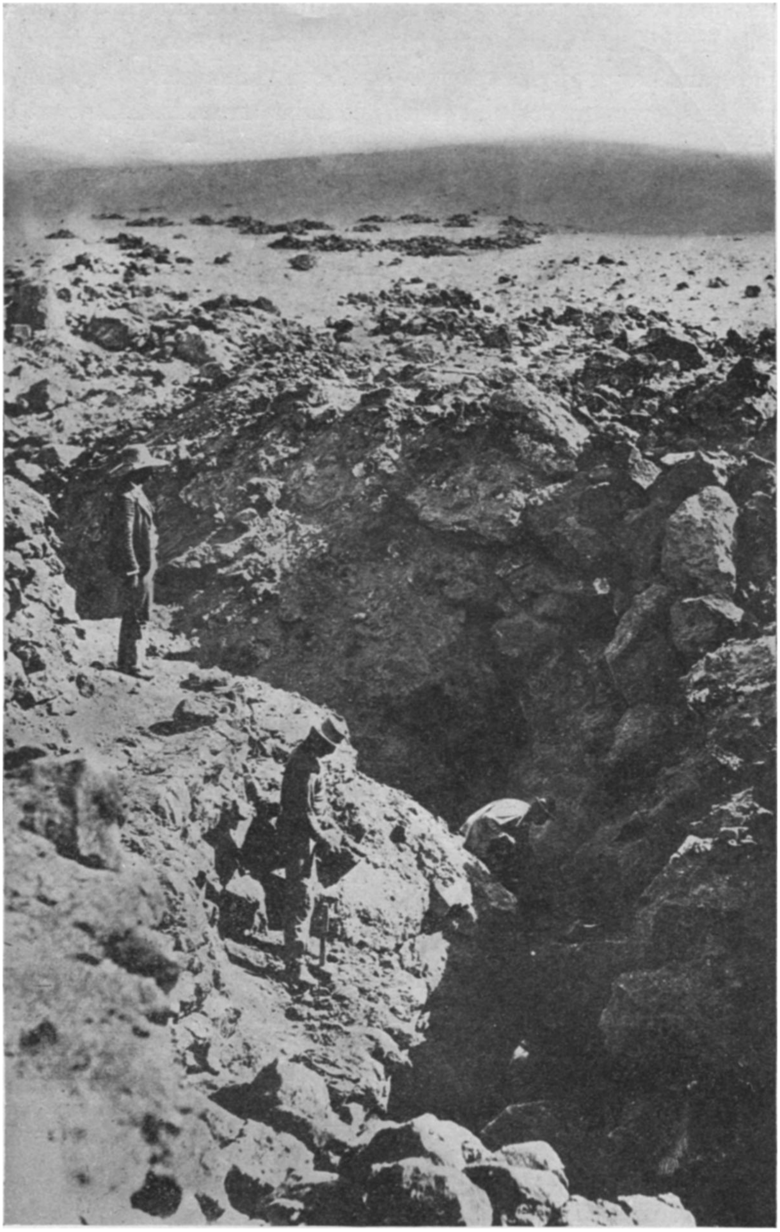

FIG. 4.—Nitrate mining in the province of Tarapacá, Chile.

often goes over the property again more carefully in search of what is left. In this way many properties have been worked over several times, and lower-grade material has been taken each time. In a few cases, even the costra, when it contains an unusual amount of nitrate, has been used after the purer parts of the deposits have been exhausted.

In the early days, only the richest of the deposits were worked, and only crude nitrate running as high as 40 or 50 per cent. in sodium nitrate was mined, but now much lower grades are worked, and the average of the crude material used in the Tarapacá region today would run, perhaps, below 25 per cent. in nitrate. Of course both richer and poorer material is also worked, and in certain places crude nitrate running even as low as 10 per cent. is utilized in admixture with higher-grade material.

The crude nitrate is hauled in carts or on tramways from the mines to the refineries, where it is coarsely crushed and the nitrate separated from the impurities by a process of leaching with hot water. The refined product usually contains about 95 per cent. of sodium nitrate, which is the standard of purity for the nitrate shipped from the district. Sometimes a still higher-grade product is made for special purposes. The nitrate is put in large sacks, and sent to the coast for shipment to various parts of the world. Sodium nitrate is deliquescent, so that when exposed to the moist air on board ships it cakes and the sacks stick together, often forming a solid mass which has to be taken out of the ships with picks.

The method used in extracting the nitrate is very crude, only from 60 to 70 per cent. of it being saved, and the average loss of nitrate in the Tarapacá region in refining is said to be about 35 per cent. Those in authority claim that under present conditions, the nitrate that is lost could not profitably be saved, but the time may come when the crude nitrate will show signs of exhaustion, and then probably less wasteful methods will be devised, and the loss will be cut down. At present, the supply of crude material is so vast that such economy has not been forced on the producers.

The iodine is obtained from the solution (mother liquor), after the nitrate has been taken out, by concentrating it and treating it with sodium sulphites, which precipitate a black powder consisting

mostly of iodine. This is then sublimed and condensed, when it is deposited in black scaly flakes of crystalline iodine.

FIG. 5. Nitrate mining in the province of Tarapacá, Chile.

The water for the nitrate works is obtained mostly from wells in the pampa, and is often gotten in considerable quantities at depths

of from 50 to 100 feet. Some water is also obtained by piping from the foot of the Andes.

Companies, towns, cities, and railways.—The nitrate industry is carried on largely by companies, and the establishments at which their operations are conducted are known as *oficinas*. Among some of the best-known oficinas in Tarapacá are the Alianza, Agua Santa, Camiña, Josefina, La Granja, Central Lagunas, North Lagunas, South Lagunas, Puntunchara, Puntilla de Huara, Rosario de Huara, Ramírez, Santa Lucía, Santiago, Unión, and many others. In 1907 there were almost one hundred oficinas in the Tarapacá region and about one hundred and fifty in all Chile (see Fig. 6).

Many small towns have grown up on the Tarapacá Pampa as a result of the nitrate industry, among them being Dolores, Santa Catalina, Negreiros, Huara, Pozo Almonte, La Noria, Lagunas, Tapiga, San Antonio, etc. The oficinas that are not at any of the towns have become small communities in themselves, with large capacious buildings for the administration of the works, houses for the employees, stores, schools, etc.

The chief ports for the shipment of the nitrate of the province of Tarapacá are Iquique on the south and Pisaqua on the north, the former being by far the more important and the real headquarters of the nitrate trade of this province. They are both connected with the nitrate fields by railway. Iquique is a flourishing city of about 50,000 inhabitants (see Fig. 7), and Pisaqua has about 5,000. Smaller ports from which Tarapacá nitrate is shipped are Junín and Caleta Buena, both lying between Iquique and Pisaqua. Farther south, the seaports of Tocopilla, Antofagasta, Taltal, etc., are important shipping-points for the nitrates of the province of Antofagasta.

The Nitrate Railways Company (an English corporation) owns a line running inland from Iquique to the Tarapacá Pampa and then branching out through the nitrate fields. It intersects the pampa from Pisaqua on the north to Lagunas on the south, a distance in a straight line of over one hundred miles and much farther as the railroad goes, besides having many lateral branches, its aggregate length being about three hundred miles. Many of the nitrate works located to one side or the other of the railroad are connected with it by branch

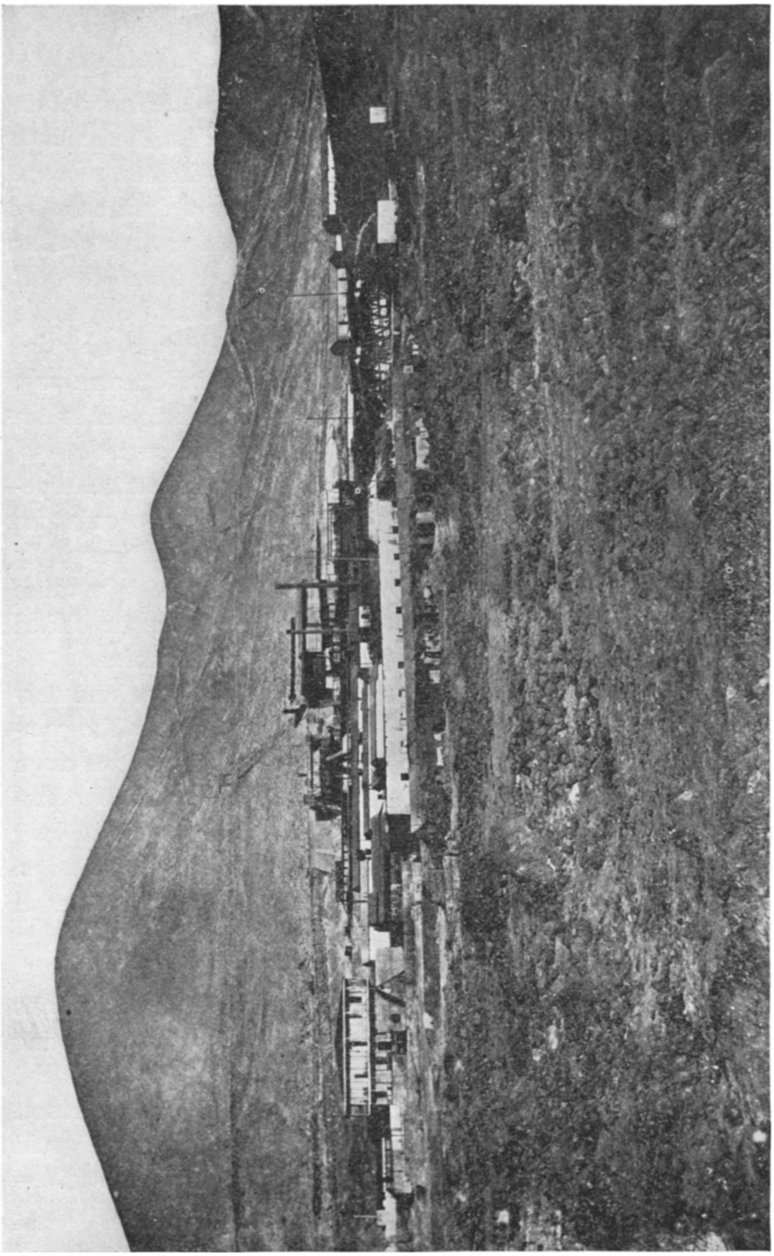

FIG. 6.—Nitrate works in the province of Tarapacá, Chile.

lines or by tramways worked by mules, and some of the nitrate companies have their own railways to the coast.

Nitrate production.—For a large part of the time in recent years, most of the large nitrate producers have been in a combination (Combinación Salitrera), which limits the output of refined nitrate and apportions to each company the amount that it may produce annually. This combination has been broken more than once by dissensions among the producers, and as late as March, 1909, after it had been in force for several years, it was again broken. Recent reports, however, are to the effect that strong efforts are being made to renew it. The object of the combination is to keep up the price of nitrate; and the production of iodine is controlled in the same way. The market for iodine is so limited that usually in a few months one company can produce enough to supply its allotment for several years. An organization is maintained to promote the use of nitrate, especially in agriculture, and agents are kept in all the large countries of the world. As a result, the consumption of nitrate is rapidly increasing, and the amount each company is allowed to produce increases correspondingly. The product goes largely to the United States and Europe, with smaller quantities to other countries.

In 1830 the production of nitrate in Chile is said to have been only 8,348 long tons.[1] In 1900 it was 1,473,091 long tons.[2] The combination of nitrate producers now estimates the production from April 1 of one year to March 31 of the following year. The production in this period from 1907 to 1908 was about 1,780,818 long tons, and from 1908 to 1909 it was about 1,808,986 long tons. The value of nitrate varies from year to year, but the price landed in New York or European ports in recent years has ranged between about $40 and $50 per long ton.

Nitrate reserves, taxes, etc.—Numerous estimates have at various times been made to determine the amount of crude nitrate existing in the nitrate regions. These estimates have differed very widely, some showing that the supply would be exhausted at the present rate of consumption in twenty-five or thirty years, others that it would last for three or four hundred years. The cause of this great diver-

[1] *Engineering and Mining Journal*, February 23, 1901, pp. 241, 242.

[2] *The Mineral Industry for 1901*, New York, 1901, p. 588.

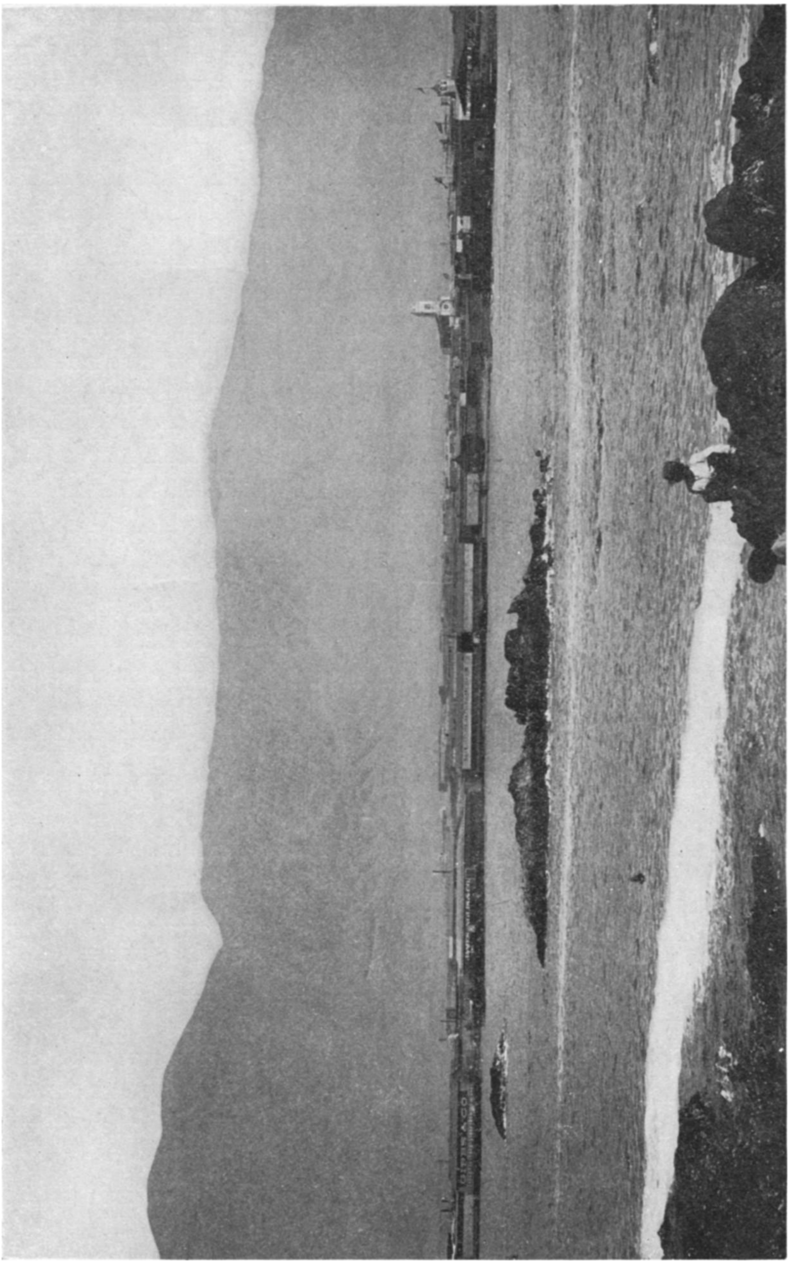

FIG. 7.—The city of Iquique, Chile.

gence is due to the premises on which the different estimates have been based. Many of those who predict a short life for the nitrate fields do not allow anything for future new discoveries of nitrates in northern Chile, whereas the probability of this is very great. The Chilean government owns all the nitrate deposits on the public domain and sells them only at auction. This policy has tended somewhat to retard individual effort at exploration, and hence vast regions in the Tamarugal Desert and the Desert of Atacama, which may contain nitrate, have not yet even been explored for it.

The nitrate that is being worked today, moreover, is very wastefully treated, and a large percentage of it is left in the refuse material accumulating around the oficinas; while the costra, or capping of the nitrate deposits proper, which is now only occasionally used as a source of nitrate, as it usually contains too low a percentage to satisfy the present operators, is collecting in vast quantities in the places where it has been mined and piled up to get at the purer material (caliche) below. Thus low-grade nitrate materials are gradually accumulating in immense amounts, and may be used in the future when more economical methods are introduced. These materials, together with the possible new discoveries of nitrate, render the future of the industry in Chile much more hopeful than some of the pessimistic prophets would lead us to believe; and for very many years to come Chile will doubtless be capable of supplying nitrate to the world.

As already stated the Chilean government owns all the nitrate lands on the public domain, and sells them at public auction from time to time, as occasion demands. The government also levies an export tax assessed in Chilean pesos. As the rate of exchange for the peso varies greatly from time to time, the amount of the tax as expressed in American money also varies greatly. A recent statement makes the tax equal to about 56 cents American money per quintel of 101.4126 pounds.[1] The combined revenues from the sales of nitrate lands and from taxes are so great that they pay a large part of the government expenses.

Uses of nitrate.—The nitrate of Chile is used for a number of

[1] These figures were kindly furnished the writer by Mr. Francisco J. Yánes, secretary of the International Bureau of American Republics, Washington, October, 1909.

different purposes, but by far the largest consumption is its use as an agricultural fertilizer, in supplying nitrogen to the soil. One of its earliest uses, and still a source of large consumption, is in the manufacture of niter, or potassium nitrate, for gunpowder. This is done by treating sodium nitrate with a salt of potassium. The nitrate of Chile is also used in the manufacture of nitric acid, and as nitric acid is an important factor in the manufacture of nitro-glycerine, dynamite, and other explosives, the consumption of Chile nitrate for such purposes is large. It is also used for many other chemical purposes on a smaller scale.

The value of sodium nitrate as a source of nitrogen in fertilizers has been known for a long time, but it has been only in comparatively recent years that it has been used on a very large scale. Formerly the nitrogen in fertilizers was supplied mostly from guano, fish scrap, leather scrap, and various other organic materials. The consumption of sodium nitrate in fertilizers now exceeds by many times its use for other purposes, and is rapidly increasing. The exhausted soils of Europe and of some parts of the United States, as well as of other countries, require year by year more fertilizing materials to make up for what is taken away by excessive cultivation, and some available compound containing nitrogen is one of the most important of such materials. Sometimes nitrate is used alone in cases where a nitrogenous compound is all that is needed, but more commonly it is used in admixture with phosphates, potassium salts, and other materials usually needed by depleted soils.

NITRATE DEPOSITS ELSEWHERE THAN CHILE

In parts of the world other than Chile, deposits of nitrates, especially potassium nitrate, and in smaller amounts calcium nitrate, have been found in many places, but nowhere in quantities in any way comparable with the sodium nitrate deposits of Chile, which today supply most of the world's demand. In old times, however, before this source became of commercial importance, potassium nitrate was obtained in considerable quantities in India and other tropical countries, where it occurs, often in association with calcium nitrate, in the soil and the grounds surrounding dwellings. Nitrate was also obtained in many parts of the world in caves, where it is found in

association with bat guano. In some cases, where these caves are in limestone, the nitrate occurs in the form of calcium nitrate, which was probably produced by the oxidation of the nitrogenous materials of the bat guano and the subsequent action of these oxidized products on the limestone. As caves in limestone are very common, the occurrence of calcium nitrate is frequently observed. In the old days nitrate was also made artificially from organic refuse in what were known as niter heaps. These produced mostly calcium nitrate, which was then converted to potassium nitrate. The nitrates in the soils of India and in the niter heaps were derived from nitrogenous animal matter, just as the cave nitrates were derived from guano, and the process in all these cases was made possible by the agency of certain bacteria already described in this paper (see p. 18).

In California, nitrate deposits occur in the arid region of the southeastern part of the state, in San Bernardino and Inyo counties, and elsewhere. The conditions there are not unlike those of northern Chile, the region consisting of high arid basins bordered by mountain ranges. The nitrate is mostly in the form of sodium nitrate, though some potassium nitrate occurs, and is associated with common salt (sodium chloride) and other saline materials, very much as in Chile. As yet these deposits have not become of much commercial value.

In recent years efforts have been made to obtain nitrogen from the air and to convert it to nitrates or other nitrogen compounds available for commercial purposes. The atmosphere contains nitrogen in the proportion of approximately 79 parts to the 100. This nitrogen, as has long been known, can be oxidized by electrical and other methods and converted to nitrates and other salts of nitrogen. Numerous methods for this operation have been devised, but their discussion is beyond the scope of the present paper, and the reader is referred to the readily accessible literature on the subject for further information.